Quantitative analysis of continuous intracranial pressure recordings in symptomatic patients with extracranial shunts

P K Eide

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Correspondence to:
Dr Per Kristian Eide,
Department of
Neurosurgery, The
National Hospital,
Sognvannsveien 20,
N-0027 Oslo, Norway;
per.kristian.eide@
rikshospitalet.no

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Objectives: To explore the outcome of management of possible shunt related symptoms using intracranial pressure (ICP) monitoring, and to identify potential methodological limitations with the current strategies of ICP assessment.

Methods: The distribution of persistent symptoms related to extracranial shunt treatment was compared before and after management of shunt failure in 69 consecutive hydrocephalic cases. Management was heavily based on ICP monitoring (calculation of mean ICP and visual determination of plateau waves). After the end of patient management, all ICP curves were re-evaluated using a quantitative method and software (Sensometrics™ pressure analyser). The ICP curves were presented as a matrix of numbers of ICP elevations (20 to 35 mm Hg) or depressions (–10 to –5 mm Hg) of different durations (0.5, 1, or 5 minutes). The numbers of ICP elevations/depressions standardised to 10 hours recording time were calculated to allow comparisons of ICP between individuals.

Results: After ICP monitoring and management of the putative shunt related symptoms, the symptoms remained unchanged in as many as 58% of the cases, with the highest percentages in those patients with ICP considered normal or too low at the time of ICP monitoring. The quantitative analysis revealed a high frequency of ICP elevations (20 to 35 mm Hg lasting 0.5 to 1 minute) and ICP depressions (–10 to –5 mm Hg lasting 0.5, 1, or 5 minutes), particularly in patients with ICP considered normal.

Conclusions: The value of continuous ICP monitoring with ICP analysis using current criteria appears doubtful in the management of possible shunt related symptoms. This may reflect limitations in the strategies of ICP analysis. Calculation of the exact numbers of ICP elevations and depressions may provide a more accurate description of the ICP profile.

Some hydrocephalic patients with extracranial shunts present with persistent symptoms such as headache, nausea, and lethargy that may indicate shunt dysfunction and abnormal intracranial pressure (ICP). It has been suggested that continuous ICP monitoring may be helpful in these cases, as similar symptoms may be related to various different types of ICP abnormality.^{1–4} However, putative shunt related symptoms may be difficult to treat despite the use of ICP monitoring.

Currently, assessment of continuous ICP recordings relies primarily on the determination of baseline or mean ICP as well as on the identification of plateau waves by visual inspection of the curve. For many years it has been common to consider a mean ICP of 10 mm Hg or less as normal, between 10 and 15 mm Hg as borderline, and above 15 mm Hg as abnormal.^{3–6} These criteria are broad. With regard to criteria for plateau waves, there are discrepancies in published reports.^{3–8} Lundberg's type A plateau waves⁸ are considered abnormal, and most investigators have defined them as rises in ICP above 50 mm Hg lasting for several minutes.⁹ There is more controversy over the identification of B waves (rises of up to 50 mm Hg lasting for 0.5 to 1 minute).^{10–13} Problems with applying these criteria to patients with shunt failure are related to the fact that mean ICP is usually normal or borderline (< 15 mm Hg), type A plateau waves are seldom observed, and there are problems in quantifying the frequency of B waves.

This study was undertaken to explore the role of ICP monitoring in the management of patients with possible shunt related symptoms. First, the frequency of symptoms was examined in the different management groups before and after ICP monitoring. The ICP curves were assessed according to conventional criteria. Second, after the end of patient management, all

ICP curves were analysed quantitatively using a computer based method,^{14–16} to explore potential limitations with the current strategies of ICP assessment.

METHODS

Patients

The study involved 69 consecutive cases undergoing continuous ICP monitoring because of suspected extracranial shunt failure during the four year period from February 1997 to March 2001. Possible shunt related symptoms were defined as persistent symptoms indicating an abnormal ICP (intracranial hypertension or hypotension) in hydrocephalic cases with an extracranial shunt. Patient data and data about decision making at the time of ICP monitoring were derived from the patients' records.

During the four year period from 1997 to 2001, the total number of shunt revisions was 716 in this department (189 in 1997, 234 in 1998, 157 in 1999, and 136 in 2000). Thus the present sample of 69 cases represents a small proportion of the total number of extracranial shunt failures. In the present cases, the median number of shunt revisions undertaken before ICP monitoring was three, with a range from 0 to 16.

Study design

The study was in two parts. First, the outcome of management of shunt related symptoms by ICP monitoring was examined, using conventional methods of ICP assessment. Second, all ICP curves were analysed quantitatively to explore the ICP profile more accurately in the different management groups.

In the first part of the study, the 69 patients were divided into three management groups. Management was heavily based on results of continuous ICP monitoring. The three groups were as follows:

- Group 1 included the 46 patients in whom the ICP recordings were considered normal, and no treatment was given.
- Group 2 included the 14 patients in whom the ICP recordings were considered abnormally reduced. In these cases action was taken to prevent overdrainage and to increase ICP (that is, by implantation of an antishunt device and valve replacement in seven cases, and by valve replacement only in the other seven).
- Group 3 included the nine patients in whom the ICP recordings were considered abnormally increased. In these cases action was taken to reduce the ICP (that is, by calvarial expansion surgery in three cases, by ventricular catheter replacement in four cases, and by valve replacement in two cases).

At the time of ICP monitoring, the assessment of ICP was according to the following criteria. A mean ICP below 10 mm Hg was considered normal, between 10 and 15 mm Hg borderline, and above 15 mm Hg abnormal, as previously described.^{3,5,6} In addition, a visual inspection of the ICP curve for the detection of plateau waves⁸ was done. In this department, rises above 50 mm Hg lasting for several minutes have been considered as plateau (A) waves. The significance of rises in ICP between 20 and 50 mm Hg of short durations (0.5 to 1 minute, corresponding to B waves) have been unclear, with no strict criteria about what might be considered abnormal.

In the second part of the study, all continuous ICP recordings were analysed quantitatively. This was done to explore the ICP profile in the various management groups. The quantitative analysis was performed after the end of patient management, as the software was not available at the time of the ICP monitoring.

Sampling and storage of intracranial pressure and software description

The methods and equipment used for digital sampling and storage of continuous ICP recordings have been described previously.^{14–16} A minimal opening was made in the dura and a Codman[®] pressure sensor (MicroSensor[™], Johnson & Johnson, Raynham, Massachusetts, USA) was introduced into the brain parenchyma. The pressure sensor was coupled to a Codman[®] pressure apparatus (Codman ICP Express[™], Johnson & Johnson), which in turn was coupled to a Siemens 9000 XL series vital signs monitor (Siemens Medical Systems Inc, Danvers, Massachusetts, USA). The ICP signals were digitised in the Siemens 9000 XL monitor and sampled at five second intervals (EWICUM streamer reader tool, Ewicum AS, Oslo, Norway). The software was developed using LabVIEW version 5.0 (National Instruments Co, Texas, USA).

The software used for quantitative analysis of the ICP data (Sensometrics[™] pressure analyser, version 1.2; Sensometrics AS, Oslo, Norway) has been described previously in detail.^{14–16} This software was also developed using LabVIEW (version 5.1). The calculation of numbers of ICP elevations of different levels and durations was done using the peak detection function. The data required for analysis include the ICP recordings as well as the width (time expressed in seconds) and threshold levels (ICP expressed in mm Hg). After the ICP curve was visualised in the user interface, a suitable width/threshold matrix was selected, specifying the width/threshold combinations. In this study, the software recorded the numbers of samples that fitted a given combination of width (0.5, 1, or 5 minutes) and thresholds (–10, –5, 20, 25, 30, or 35 mm Hg). The output from the analysis was a matrix containing the numbers of the different width and threshold combinations. As the actual ICP recording period during sleep or in the awake state varied between cases, calculation of width/threshold combinations during a standardised recording time of 10 hours was undertaken. During the awake state the patient was allowed to sit or stand up.

Statistics

The data calculated by the software were saved as ASCII (American standard code for information interchange) files, and transferred to Microsoft Excel version 97 for statistical analysis. The computer program PC-SPSS, version 9.0 (SPSS Inc, Chicago, Illinois, USA) performed the statistical analysis. Non-parametric tests were used. Comparisons between two independent samples were done by the Mann–Whitney test. Comparisons were only done when there were eight or more patients in each group. Two tailed probability (p) values were calculated.

RESULTS

Management and outcome of shunt failure at the time of ICP monitoring

As indicated in table 1, in the 69 patients with persistent putative shunt related symptoms, ICP was considered normal in 46 cases (group 1), abnormally low in 14 cases (group 2), and abnormally increased in nine cases (group 3). In groups 1 and 2, mean ICP during sleep was either normal (< 10.0 mm Hg) or borderline (10.0 to 15.0 mm Hg). In group 3, mean ICP during sleep was either considered borderline or abnormally increased (> 15.0 mm Hg). Visual inspection of the ICP curves showed no plateau (A) waves of 50 mm Hg lasting several minutes. The frequency of B waves also contributed to the diagnosis; however, B wave assessment is observer dependent and was not systematically evaluated.

The continuous ICP recordings had a low predictive value for patient management. Elevated ICP was suspected in 45 of the 69 cases (65%), but was considered as confirmed in only eight. Too low ICP was suspected in 24 cases (35%), but was considered as confirmed in only 10. After a median observation time of 12 months (range 1 to 37 months), persistent symptoms were observed in as many as 40 of the 69 cases (58%)—in 65% of the cases in group 1 and in 57% in group 2.

Complications of ICP monitoring were observed in three of the 69 cases (4.4%). In a 12 month old boy, ICP monitoring caused meningitis which was treated with systemic antibiotics and external ventricular drainage. The treatment was ended after two weeks and a new ventriculo-peritoneal shunt inserted. The boy has not required any further shunt revisions over the observation period of 12 months. In a 13 year old boy, a local wound infection developed that required a local treatment for some days. In a 10 year old girl, a signal change was observed on computed tomography (CT) at the site of the ICP sensor. There was no evidence of haemorrhage and this finding was not associated with symptoms.

Linear measures of ventricular size by cranial CT revealed no differences in ventricular size between the different management groups.

Retrospective quantitative analysis of the continuous ICP recordings

The quantitative analysis of the ICP recordings was done retrospectively. Examples are given in figs 1 to 3. Figure 1 shows the ICP curves of two cases in group 1, both with a mean ICP below 12.0 mm Hg. Quantitative analysis revealed a rather high frequency of ICP elevations. Symptoms remained unchanged in both cases.

Figure 2 shows the ICP curves during the awake state of two cases with a low mean ICP. Though mean ICP was comparable in these two cases (2.2 v 1.7 mm Hg), the quantitative analysis showed a large number of ICP depressions in case B (24 episodes of ICP –5 mm Hg lasting five minutes or more during a standardised recording time of 10 hours). In this case, the ICP was considered normal, no action was taken, and symptoms remained unchanged.

Figure 3 shows the ICP recordings during the awake state of two cases of group 1, in whom mean ICP was 2.1 and 9.4 mm

Table 1 Demographic and clinical data at the time of intracranial pressure monitoring

	Total	Group 1	Group 2	Group 3
Total number of patients	69	46	14	9
Male/female	40/29	29/17	7/7	4/5
Age (months) at ICP monitoring				
Median (range)	66 (12 to 358)	65 (12 to 358)	93 (20 to 255)	46 (21 to 234)
Clinical symptoms before ICP monitoring				
Headache	41 (59)	26 (57)	9 (64)	6 (67)
Irritability	29 (42)	21 (46)	4 (29)	4 (44)
Nausea	19 (28)	10 (22)	3 (21)	6 (67)
Lethargy	24 (35)	18 (39)	3 (21)	3 (33)
Epileptic seizures	9 (13)	5 (11)	3 (21)	1 (11)
Positional symptoms				
Relief by lying down	15 (22)	7 (15)	7 (50)	1 (11)
Relief by sitting up	7 (10)	5 (11)	2 (14)	
Worsening by lying down	5 (7)	3 (7)	2 (14)	
Worsening by sitting up	5 (7)	1 (2)	4 (29)	
Day and night variation in symptoms				
Worst in the morning	5 (7)	3 (7)		2 (22)
Worst in the evening	5 (7)	2 (4)	2 (14)	1 (11)
Worst in the night	6 (9)	5 (11)		1 (11)
Clinical indications for ICP monitoring				
Clinically suspected increased ICP	45 (65)	33 (72)	4 (29)	8 (89)
Clinically suspected reduced ICP	24 (35)	13 (28)	10 (71)	1 (11)
Mean ICP during sleep				
<10.0 mm Hg	37 (54)	24 (52)	13 (93)	
10.0 to 15.0 mm Hg	28 (41)	22 (48)	1 (7)	5 (56)
>15.0 mm Hg	4 (6)			4 (44)
Mean ICP during the awake state				
<10.0 mm Hg	56 (81)	41 (89)	13 (93)	2 (22)
10.0 to 15.0 mm Hg	8 (12)	5 (11)	1 (7)	2 (22)
>15.0 mm Hg	5 (7)			5 (56)
Outcome after management				
Relief of symptoms	29 (42)	16 (35)	6 (43)	7 (78)
Lasting and unchanged symptoms	40 (58)	30 (65)	8 (57)	2 (22)

Data presented as absolute numbers. The percentages are given in parenthesis and represent the proportions of numbers within each group.
ICP, intracranial pressure.
Group 1, "normal" mean ICP; group 2, "low" mean ICP; group 3, "high" mean ICP.

Hg, respectively. The matrix shows both a large number of ICP elevations above 20 mm Hg and a large number of ICP depressions below -5 mm Hg.

Comparisons of numbers of ICP elevations between the different management groups are presented in table 2. The most important observation was that a rather high frequency of ICP elevations of 20 to 35 mm Hg lasting 0.5 to 1 minute was found in the cases in group 1. This trend was more obvious during sleep than during the awake state. For example, in group 1 during sleep, ICP elevations of 25 mm Hg lasting one minute occurred in 22 of the 46 cases (48%).

Comparisons of ICP depressions between the different management groups are presented in table 3. The major observation is that reductions in ICP of -10 to -5 mm Hg lasting 0.5, 1, or 5 minutes were quite frequent in group 1. For example, during the awake state, depressions in ICP of -5 mm Hg lasting one minute were observed in 15 of the 46 cases (33%) in group 1. Depressions of ICP occurred more commonly during the awake state than during sleep, owing to the fact that the patients were sitting or standing up during the awake state.

The frequency of ICP depressions was explored in comparable patient material, including 135 cases undergoing ICP monitoring for suspected craniosynostosis or hydrocephalus

(unpublished data). None of the cases had an extracranial shunt. The numbers of ICP depressions during a standardised recording period of 10 hours during the awake state were as follows:

- n (-5 mm Hg/0.5 min) = 16 (11.9%); median number of depressions, 2 (range 1 to 7);
- n (-5 mm Hg/1.0 min) = 9 (6.7%); median number of depressions, 1 (range 1 to 5);
- n (-5 mm Hg/5 min) = 1 (0.7%); median number of depressions, 1 (range 1 to 1).

Comparisons of ICP depressions of -5 mm Hg between this group of 135 cases and the cases in group 1 showed significant differences in the numbers of depressions lasting 0.5 minutes ($p = 0.002$) or 1 minute ($p = 0.001$) (Mann-Whitney test).

DISCUSSION

Continuous ICP monitoring in cases with shunt related symptoms

In hydrocephalic cases treated with extracranial shunts, persistent symptoms of abnormal intracranial pressure may sometimes indicate shunt failure. Several investigators have shown previously that symptoms indicating extracranial

Figure 1 Intracranial pressure (ICP) curves during sleep for two cases in group 1 ("normal" mean ICP). To the left is the ICP curve of a 10 year, 4 month old girl with headache and lethargy (case A). To the right is the ICP curve of a 17 year, 10 month old girl with headache (which was reduced by lying down) and dizziness (case B). Mean ICP was 11.8 mm Hg in case A and 10.4 mm Hg in case B. The corresponding matrix presents the numbers of ICP elevations (20 to 35 mm Hg) and depressions (-10 to -5 mm Hg) lasting 0.5, 1.0, or 5.0 minutes during a standardised recording time of 10 hours.

Figure 2 Intracranial pressure (ICP) curves during the awake state in two cases. To the left is the ICP curve of an 8 year, 10 month old girl in group 2 ("low" mean ICP) with headache (case A). To the right is the ICP curve of a 4 year, 9 month old boy in group 1 ("normal" mean ICP) with headache, anorexia, and lethargy (case B). Mean ICP was 2.2 mm Hg in case A and 1.7 mm Hg in case B. The corresponding matrix presents the numbers of ICP elevations (20 to 35 mm Hg) and depressions (-10 to -5 mm Hg) lasting 0.5, 1.0, or 5.0 minutes during a standardised recording time of 10 hours.

shunt failure (headache, irritability, nausea, vomiting, and lethargy) may result from different underlying causes.¹⁻⁴ The authors suggested a role for ICP monitoring in patients with shunt failure, though the numbers of patients in their studies were quite small. The first part of the present study, however, did not suggest a particularly useful role for ICP monitoring in extracranial shunt failure. Among the 69 patients, symptoms remained unchanged in 58% despite using ICP monitoring. In the 46 patients whose ICP was considered normal (group 1), symptoms remained unchanged in 65%; the percentages were 57% and 22% in groups 2 and 3, respectively.

The patients in this study with putative shunt related symptoms represent a small subgroup of shunt failure patients. In most cases shunt failure is straightforward to diagnose on the basis of symptoms and radiological findings. During the period when the present cases were tested, 716 shunt revisions were done in the same department.

There could be several reasons for the high frequency of persistent symptoms despite the use of ICP monitoring. First, symptoms might not be related to shunt malfunction in some cases. In general, invasive and in vivo testing of the hydrodynamic properties of the shunt may be required to test whether symptoms suggestive of shunt malfunction are in fact due to

Figure 3 Intracranial pressure (ICP) curves during the awake state for two cases in group 1. To the left is the ICP curve of a 3 year, 5 month old boy with irritability, transient abducens paresis, and nausea (case A). To the right is the ICP curve of a 4 year, 1 month old boy with headache and lethargy (case B). Mean ICP was 2.1 mm Hg in case A and 9.4 mm Hg in case B. The corresponding matrix presents the numbers of ICP elevations (20 to 35 mm Hg) and depressions (-10 to -5 mm Hg) lasting 0.5, 1.0, or 5.0 minutes during a standardised recording time of 10 hours.

Table 2 Comparison of intracranial pressure elevations of different levels and durations in the different groups of patients

		Level of ICP elevations							
Duration of ICP elevations	Management groups	20 mm Hg		25 mm Hg		30 mm Hg		35 mm Hg	
		N (%)	Median (range)	N (%)	Median (range)	N (%)	Median (range)	N (%)	Median (range)
Sleep state									
0.5 min	Group 1	33 (72)	22 (1 to 121)	27 (59)	7 (1 to 64)	20 (43)	5 (1 to 50)	14 (30)	2 (1 to 22)
	Group 2	5 (36)	2 (1 to 25)	2 (14)	4 (2 to 5)	2 (14)	1 (1 to 2)	1	2 (2 to 2)
	Group 3	9 (100)	186 (15 to 765)‡	8 (89)	107 (1 to 233)*	8 (89)	43 (1 to 100)*	6 (67)	15 (3 to 58)
1 min	Group 1	30 (65)	15 (1 to 79)	22 (48)	6 (1 to 36)	17 (37)	3 (1 to 25)	9 (20)	2 (1 to 13)
	Group 2	3 (21)	4 (1 to 15)	1	3 (3 to 3)	1	2 (2 to 2)	1	2 (2 to 2)
	Group 3	9 (100)	86 (2 to 560)*	8 (89)	55 (1 to 148)*	7 (78)	26 (1 to 51)	6 (67)	5 (1 to 30)
Awake state									
0.5 min	Group 1	30 (65)	10 (1 to 166)	21 (46)	8 (1 to 92)	12 (26)	9 (2 to 42)	12 (26)	4 (2 to 9)
	Group 2	5 (36)	5 (2 to 58)	3 (21)	3 (3 to 40)	3 (21)	3 (1 to 27)	1	6 (6 to 6)
	Group 3	9 (100)	232 (20 to 684)§	9 (100)	57 (5 to 296)†	6 (67)	26 (2 to 63)	4 (44)	10 (6 to 18)
1 min	Group 1	22 (48)	10 (1 to 107)	13 (28)	7 (1 to 55)	10 (22)	3 (2 to 18)	8 (17)	2 (1 to 5)
	Group 2	3 (21)	10 (1 to 33)	2 (14)	10 (1 to 19)	1	10 (10 to 10)	1	4 (4 to 4)
	Group 3	9 (100)	140 (12 to 422)§	9 (100)	27 (2 to 174)	5 (56)	13 (8 to 37)	4 (44)	6 (3 to 18)

Percentages of cases within each group presented in parentheses. Numbers of ICP elevations during a standardised recording time of 10 hours presented as median numbers with ranges in parentheses.

* $p < 0.05$; † $p < 0.01$; ‡ $p < 0.005$; § $p < 0.001$ (Mann-Whitney test).

ICP, intracranial pressure.

Group 1, "normal" mean ICP; group 2, "low" mean ICP; group 3, "high" mean ICP.

this cause.¹⁷ However, as this approach is not available in most departments, the clinical diagnosis of shunt malfunction commonly relies on symptoms with or without radiological findings. In the patients reported here, the symptoms were persistent and considered to be related to shunt malfunction by both the doctor and the patients or the patients' parents.

Second, the patient population was heterogeneous. Different types of shunt dysfunction were probably involved. It seems difficult to relate symptoms to a particular type of shunt failure. However, in group 3 the assumed intracranial hypertension was treated with calvarial expansion surgery in three cases, ventricular catheter replacement in four, and valve

replacement in two. Symptoms remained unchanged in fewer than one quarter of these cases. In group 2, on the other hand, the assumed intracranial hypotension was treated with implantation of an antisiphon device and valve replacement in seven cases and valve replacement only in the other seven, and the symptoms remained unchanged in two thirds of those cases.

The observation of a high frequency of persistent symptoms raises the question of whether ICP monitoring is ethically justified in these cases. Continuous ICP monitoring is accompanied by a small but definite risk. In this study, complications were observed in three of the 69 cases (4.4%), though no long

Table 3 Comparison of intracranial pressure depressions of different levels and durations in the different groups of patients

Duration of ICP elevations	Management groups	Awake state				Asleep state			
		–10 mm Hg		–5 mm Hg		–10 mm Hg		–5 mm Hg	
		N (%)	Median (range)	N (%)	Median (range)	N (%)	Median (range)	N (%)	Median (range)
0.5 min	Group 1	10 (22)	11 (1 to 257)	21 (46)	47 (1 to 508)	1	1 (1 to 1)	9 (20)	2 (1 to 19)
	Group 2	6 (43)	63 (10 to 803)	10 (71)	252 (17 to 826)*	2 (14)	3 (2 to 4)	5 (36)	4 (1 to 319)
1 min	Group 1	7 (15)	8 (1 to 149)	15 (33)	96 (1 to 284)	–	–	6 (13)	3 (1 to 11)
	Group 2	6 (43)	32 (4 to 509)	9 (64)	150 (39 to 512)	2 (14)	3 (3 to 3)	3 (21)	21 (2 to 198)
5 min	Group 1	3	14 (13 to 50)	11 (24)	27 (4 to 87)	–	–	–	–
	Group 2	5 (36)	3 (1 to 137)	9 (64)	30 (3 to 137)	–	–	2 (14)	33 (4 to 61)

Numbers of ICP reductions during a standardised recording time of 10 hours presented as median numbers with ranges in parentheses.

* $p < 0.05$ (Mann–Whitney test). No ICP reductions in group 3.

ICP, intracranial pressure.

Group 1, “normal” mean ICP; group 2, “low” mean ICP; group 3, “high” mean ICP.

lasting sequelae occurred. We previously reported complications without long term sequelae in 3.1% of a series of 127 consecutive cases undergoing continuous ICP monitoring.¹⁴ These numbers are comparable with the results of others.¹⁸

At the time of ICP monitoring, the ICP curves were assessed according to conventional criteria—that is, calculation of mean ICP combined with a visual inspection of the curves to detect plateau waves. Similar criteria to those used by others^{3, 5, 7, 11, 13} were employed to assess the mean ICP. The criteria for the various plateau waves remain problematic. Contrasting with the original description by Lundberg,⁸ type A plateau waves are described by most investigators as pressure elevations of 50 mm Hg lasting for more than five minutes.⁹ Type B waves are increases in ICP of up to 50 mm Hg lasting for 0.5 to 2 minutes.⁸ However, these waves have been difficult to quantify, as reflected by the fact that frequencies considered normal differ markedly in published reports.^{10–13, 19, 20}

The present results highlight some problems with these approaches. As many as 94% of the cases in this study had either a normal (< 10 mm Hg) or a borderline (10–15 mm Hg) mean ICP, and no classical A waves were observed. At the time of ICP monitoring, no systematic determination of B wave frequency was undertaken, as the observers found it difficult to define the frequency of these waves. The determination of B waves by visual inspection of the curves is observer dependent. Thus continuous ICP monitoring using conventional criteria often turned out to be inconclusive. At the time of monitoring, the ICP was considered normal in 46 of 69 cases (group 1). However, symptoms remained unchanged in 40 of the 69 cases.

Retrospective quantitative assessment of continuous ICP recordings

In the second part of the study, all ICP curves were analysed quantitatively in order to reveal potential methodological limitations with current strategies of ICP assessment.

The quantitative analysis of ICP presented here has been described recently.^{14–16} In this study, calculation of the numbers of ICP elevations of 20 to 35 mm Hg lasting 0.5 to 1 minute during a standardised recording time of 10 hours allowed objective and accurate comparisons between patients. The most important observation was a high frequency of ICP elevations of 20 to 35 mm Hg lasting 0.5 or 1 minute in the cases in group 1. Patients in this group were considered to have a normal ICP at the time of ICP monitoring. The frequency of ICP elevations in group 1 was comparable with the frequencies found in cases with hydrocephalus.¹⁶ The computation of short lasting ICP elevations (20 to 35 mm Hg, lasting 0.5 to 1 minute) may be comparable to the computation of B wave frequency. A tentative hypothesis is that a high frequency of the short lasting ICP elevations may

indicate intracranial hypertension, even though baseline or mean ICP remains within normal limits. However, the normal frequency and distribution of ICP elevations is not known. Thus it is not possible to conclude whether the frequency of ICP elevations in the different treatment groups was more than or less than normal. The present numbers should be compared with the numbers of ICP elevations in asymptomatic patients with shunts, but such material does not exist.

This paper also focuses on another aspect of variation in ICP, namely the so called ICP depressions. The term ICP depressions refers to potentially abnormal reductions in ICP. Reduced ICP because of overdrainage is a well known problem in patients with extracranial shunts. Abnormal ICP reductions in such patients have been described previously.^{2, 3} These reductions depend on body position and are most evident in the standing position. Accordingly, the frequency of ICP depressions was greatest during the awake state, when the patients were allowed to sit or stand, resulting in lowered ICP because of increased drainage of cerebrospinal fluid.

At present, the normal frequency of ICP depressions of –10 and –5 mm Hg lasting for 0.5, 1, or 5 minutes is not established. In an unpublished sample of 135 cases, the percentage of ICP depressions of –5 mm Hg lasting 0.5, 1, or 5 minutes during 10 hours of recording were 11.9%, 6.7%, and 0.7%, respectively. These figures show that ICP depressions are more common in shunted than in non-shunted patients. For example, ICP depressions of –5 mm Hg lasting five minutes occurred in 29% of the shunted patients in the present study, as compared with 0.7% of the 135 non-shunted patients. Furthermore, in the patients with an ICP considered acceptable at the time of monitoring (group 1), the percentage of depressions of –5 mm Hg lasting five minutes was 24%. In fact, the frequency of ICP depressions of –5 or –10 mm Hg lasting one to five minutes was not significantly different between cases in groups 1 and 2. It seems reasonable to speculate that the high frequency of ICP depressions in group 1 results from non-recognised overdrainage in some cases.

Based on the present data, it may be hypothesised that computation of numbers of ICP elevations and depressions may provide a more accurate description of the ICP curve than the more conventional assessment strategies. However, this hypothesis must be tested in a prospective study. Based on the present data it is not possible to conclude whether patient management would have been more successful if ICP had been analysed using the quantitative method compared with the conventional method.

Conclusions

In patients with possible shunt related symptoms, symptoms were persistent in a significant proportion of cases despite the use of ICP monitoring. The inadequacy of ICP monitoring in

the management of extracranial shunt failure may be related to the current strategies of assessing ICP. In cases where ICP is considered normal at the time of monitoring, a rather high frequency of short lasting ICP elevations and depressions was found. However, the role of quantitative ICP analysis in the management of shunt failure needs to be explored in a prospective study.

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